Photo-based Terrain Data Acquisition and 3D Modeling

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1 Introduction

When performing hydrologic and geomorphologic analyses for small area sites, it is desirable to capture terrain data for 3D modeling at higher resolution and lower cost than typical LiDAR imaging provides. This is especially desirable when assessing frequent or detailed terrain changes due to erosion or human activities such as agriculture, development grading, and mining. This paper explores recent advances in the application and effectiveness of relatively low-cost software that relies on modified automatic aerial triangulation techniques for modeling 3D terrain based on overlapping, multiple photographs (DUNN, 2009; REMONDINO et al., 2011).

The long term goal of this exploration is to determine if this new, relatively low-cost software might replace manual field techniques being used by landscape architects and other university researchers conducting hydrologic analyses. Gully erosion is being monitored and studied within agricultural fields and a restricted military base. In all instances, major erosion is interfering with land uses and contributing to stream sediment. Gully prediction, both in terms of formation and geomorphology, relies on accurate terrain modeling that is geo-referenced enabling periodic measurements and comparisons over time (CASTILLO et al., 2011; GESSESSE et al., 2010; SHRUTHI et al., 2011).

Preliminary investigations were conducted using three sites at three different scales to assess general applicability of photo-based 3D terrain modeling. The impetus for this initial exploration is threefold: 1) For sites 250 ha or less, determine if drainage patterns can be identified and mapped with greater precision than available from public sources offering 2 m LiDAR resolution, and lower cost than contracted LiDAR flights of higher precision or frequency; 2) Test the suitability of two different unmanned aerial platforms for low altitude data acquisition; and 3) Test whether derived terrain models are accurate enough to detect minute surface variations of 1 cm or less that might support erosion estimates.

2 Software Tool: Agisoft PhotoScan Pro

The software chosen for this investigation is PhotoScan Pro (AGISOFT, 2012). This Russian software is preferable over other 3D photo-modelers because it supports geographic or projected coordinate systems which make it suitable for photogrammetric and remote sensing applications. It is also relatively affordable: 420 Euro ($549 USD) for the academic version and 2,680 Euro ($3,500 USD) for the commercial version. FRANKENBERGER et al., (2008) and others have shown that photo-modeling software can approach the accuracy of terrestrial based LiDAR scanners.

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PhotoScan is designed to work with digital cameras. If the software cannot automatically determine the optical and format parameters of the camera lens, Agisoft also offers free software to calculate these parameters through a lens calibration routine. A camera resolution of five megapixels or greater is recommended. The software accepts the following image formats: JPEG, TIFF, PNG, BMP, JPEG Multi-Picture Format (MPO) [and RAW saved as a TIFF]. Major processing steps include photo import, photo alignment and point cloud matching, surface geometry building, texture building, ground control adjustments/ model updating, and exportation of 3D models, DEMs, and orthophotos.

3 Unmanned Aerial Systems

To increase image acquisition efficiency for larger area sites, two types of unmanned aerial systems were used for aerial photography: the RiteWingRC Zephyr (flying wing) (RITEWING, 2012) and the DJI S800 Hexacopter (UAV PRODUCTS, 2012). Both are small radio controlled vehicles and can be flown interactively or through programmed flight paths (Fig. 1). Flight duration is brief (12-18 minutes) due to battery power limitations. Both vehicles carried aloft a lightweight Canon Powershot S100 (12.1 MP) digital camera. Images were captured every four seconds and saved in both .JPG and .CR2 formats.

Fig. 1: RiteWingRC Zephyr flying wing and the DJI S800 hexacopter (Dr. Kevin Price)

In the United States, the Federal Aviation Administration (FAA) currently restricts the commercial use of unmanned aerial systems (UAS) until standards, certification, and operating procedures are in place by 2015 (FAA, 2011). After this date, widespread adoption of this technology for close range remote sensing will become more widespread. At this time, public agencies and universities can operate a UAS if a Certificate of Authorization (COA) is obtained per UAS per site, and proper flight protocols are followed.

4 Methods

To investigate the three research objectives defined in Section 1 Introduction, three test sites (TS) near Manhattan, Kansas were selected. Basic site parameters, lighting/weather conditions, and the number of ground control (GC) points used are summarized in Table 1. Table 2 provides additional data of the image collection phase.

Table 1: Test Site Summary

Test Site (TS)	Coverage Area	Land Cover	Imaging Date/Time	Images Used	GC Pts.
TS1–Field	129,112.0 m^2 (12.9 ha)	Short grass & tree patches	Nov 16/ 1:30p	9	6
TS2–Pasture Gully	792.0 m^2	Grass/dirt	Dec 4/1:00p	16	3
TS3–Eroded Slope	6.7 m^2	Bare dirt	Jan 7/1:45p	9	2

Weather for all imaging times was clear and sunny, with winds 0-5 km/hr. TS1 and TS2 were chosen because of prior COA flight clearances.

Table 2: Imaging Summary

Test Site (TS)	Acquisition Method	Camera	Altitude or Camera Dist.	Ground Resolution
TS1–Field	Zephyr	Canon S100*	195.41 m	68.85 mm/pix
TS2–Pasture Gully	Hexacopter	Canon S100*	16.06 m	4.87 mm/pix
TS3–Eroded Slope	Ground Photo	Nikon D50**	2.76 m	0.85 mm/pix

*Canon S100: 5.2 mm focal length; 4000 x 3000 resolution setting.
**Nikon D50: 18 mm focal length; 3008 x 2000 resolution setting.

TS1-Field: This site was selected to investigate if PhotoScan could detect and model subtle drainage patterns from imagery collected at low altitudes using the unmanned Zephyr flying wing. A programmed flight path provided uniform aerial coverage. Because of the ~ 60 km/hr flight speed, a limited number of images were acquired due to the four second image interval. Ground control was provided by using UTM projected Bing imagery available through ArcOnline (ESRI, 2012) for XY positioning, and using 2 m LiDAR data available through the Kansas GIS Data Access & Support Center (DASC, 2012) to estimate Z coordinates. After error correcting the 3D terrain model using ground control and applying image texturing, the model was exported in DEM and orthophoto formats. A comparison was then made in a GIS environment between the newly acquired terrain and LiDAR terrain. A sophisticated analysis was not deemed necessary for this preliminary investigation; rather, a simple visual comparison was made between hill-shaded surfaces.

TS2-Prairie Gully: A typical prairie gully section was chosen as a site to test the efficiency and effectiveness of the low flying hexacopter for image collection. The hexacopter was flown interactively down the gully section (~ 80 m long with 0.30-0.75 m vertical head cuts). Precise ground control using a surveyor's total station was not used. A sub-objective of this investigation was to determine if PhotoScan could rapidly model gullies in sufficient detail and accuracy without making future field work unduly complicated or require survey personnel. PhotoScan model accuracy was compared with the real-world gully using ten spot check measurements taken on a return field visit.

TS3-Eroded Slope: In the last investigation, a very small eroded slope was chosen to determine how well PhotoScan could resolve small surface variations over time. Aligning surfaces and calculating volume differences would enable estimating quantities of eroded soil. Procedures began by embedding two control markers, spaced 1.93 m apart, in the slope that would be included in the photographs to serve as a reference scale. Existing slope conditions were then photographed from a distance of approximately 2.76 m. The undisturbed slope was photographed a second time to serve as a control surface. Using a trowel, small quantities of soil were scraped from the slope and collected for volume measurement. Scraping depth was approximately 1-2 cm and the total soil collected was 8,000 cm^3. The scraped slope was then photographed to document "eroded" conditions.

Three surfaces were built in PhotoScan corresponding to the three sets of slope photographs. Surfaces were then aligned through the resident PhotoScan feature: "Align Chunks..." using the "Point based" option. By visual inspection, the surfaces appeared to be translated and rotated to achieve a best fit. Surfaces were then exported in both .3ds model format (triangulated mesh) and DEM raster format. All surfaces, in both formats, were imported into ESRI ArcMap software (ESRI, 2012). All surface rasters were clipped to the exact same rectangular extent to enable volumetric calculations. Any calculated differences between the two control surfaces would indicate alignment, feature resolution, or replication errors –"error noise".

5 Results

TS1-Field: Even with minimal ground control and aerial coverage photographs, the orthophoto mosaic produced through PhotoScan horizontally matched the GIS reference sources within ± 1.5 m (spot checks), although PhotoScan resolution was better than 7x7 cm. The Zephyr flying wing was also an extremely efficient method of acquiring aerial imagery (~1.4 km^2/min) with minimal preparation and setup time. With the methods employed, topographic modeling using PhotoScan was far inferior compared the lower resolution bare-earth LiDAR terrain (Fig. 2). PhotoScan failed to pick up drainage subtleties and dirt road tracings present in the LiDAR terrain. This is likely attributable to vegetation which cannot be processed out of photo-based data, too few photographs, and relatively inaccurate Z-control. In patch areas of leafless deciduous trees, accuracy was poor, or the terrain surface contained holes. The Z-difference mean between the PhotoScan and LiDAR surfaces was 1.08 m.

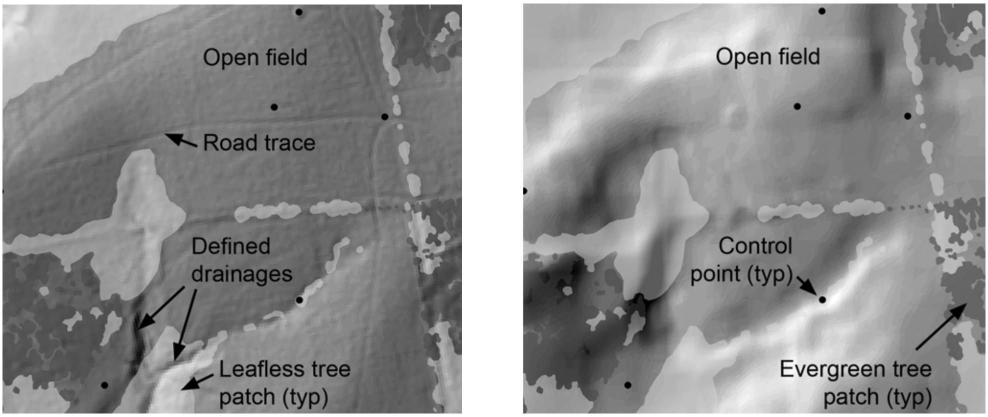

Fig. 2: Comparison of 2 m LiDAR surface (left) with 7x7 cm PhotoScan surface (right)

TS2-Prairie Gully: The lower altitude and slower speed of the hexacopter produced far better terrain modeling results than TS1 (Fig. 3). Ten random field check measurements in all XYZ orientations and distances resulted in a mean error of 3.53 cm. This is certainly within the probable error of establishing the field markers to match model reference points. At this relatively close imaging range, the 7-10 cm high grass cover did not appreciably affect relative terrain accuracy (little variation in grass height). Compared to the manual method of taking cross-sectional measurements at limited intervals along the gully flowline, the PhotoScan method offers several significant advantages:

- Fully continuous surfaces are depicted and resolved down to millimeters of detail.
- Terrain surfaces are fully textured mapped with high resolution imagery that serves as good documentation. Texture maps can be optionally turned off.
- Using the texture map as a visual guide, additional gully measurements can be made off-site at any future time.
- Digital terrain models can be imported in a GIS environment and combined with other data for a variety of analyses across different time scales.
- Texture mapped terrain models can be emailed as 3D .pdf files which can be interactively manipulated and viewed from any angle.

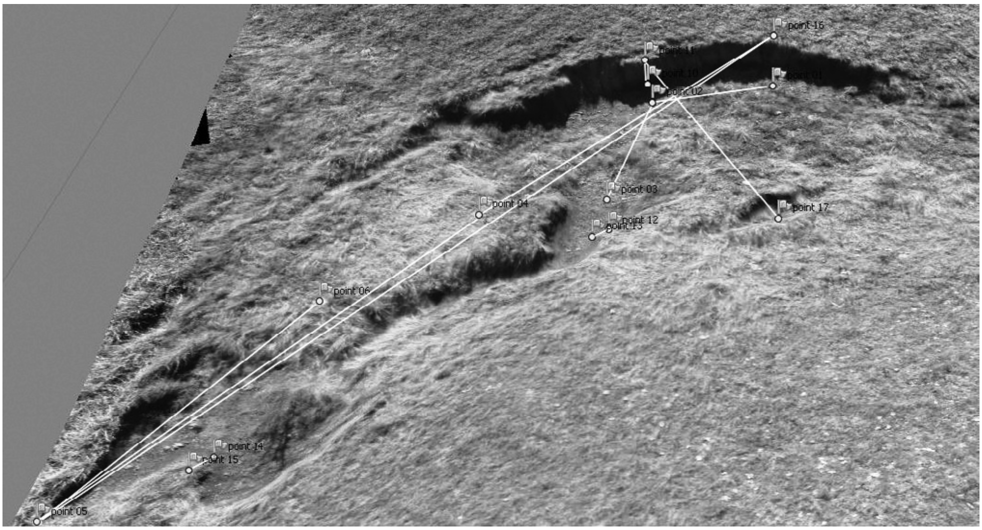

Fig. 3: PhotoScan terrain model of prairie gully with field measurement spot checks

TS3-Eroded Slope: At a close camera range of 2.76 m, PhotoScan is capable of producing a 3D model surface with a Z-resolution of 5 mm or less for bare earth conditions (Fig. 4). Eroded conditions are easily photo captured and modeled.

Subsequent volume calculations referenced the 8,000 cm^3 of scraped soil that was collected. Volumes were calculated for both the soil scraped and collected as “erosion”, and for “error noise” between two control surfaces.

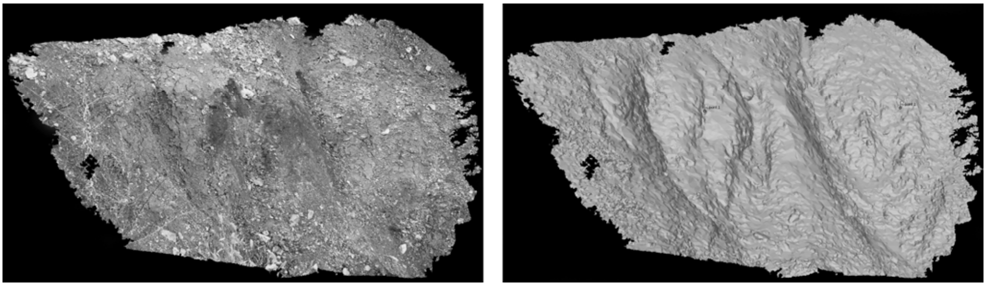

Fig. 4: PhotoScan 3D model displayed with textures (left) and as a bare surface (right)

Subtracting the scraped surface from the undisturbed surface resulted in a raw calculated volume of 10,740 cm^3 (74.5% accuracy) depicted in Fig. 5a. Direct error compensation was conducted by generating a histogram of Z differences per raster cell displayed with a natural breaks (Jenks) distribution. Filtering out apparent error noise ranges resulted in a corrected volume of 9,390 cm^3 (85.2% accuracy).

Alternatively, a second correction method was also applied. Subtracting volumetric control surfaces generated from supposedly identical photo/model sets of the same undisturbed condition, revealed a mean z-difference of 0.47 mm per raster cell. Aggregated over the entire clipped surface area, total error volume serving as the control amounted to 1,420 cm^3 (Fig. 5b). Accounting for errors revealed by the volumetric control, the net "eroded" volume is 9,320 cm^3 (85.8% accuracy).

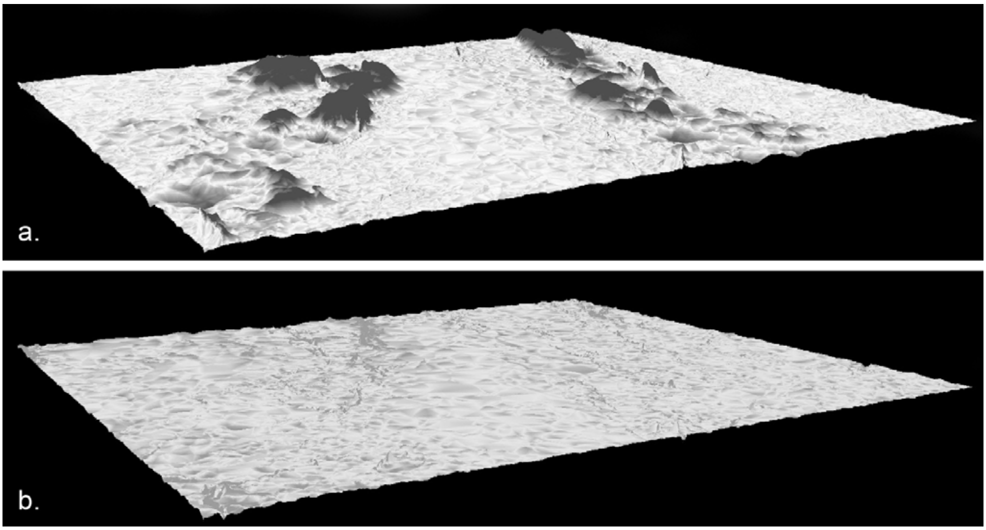

Fig. 5: Volume differences for detected "eroded" soil (5a) and error "noise" between control surfaces generated from the same undisturbed condition (5b)

Overall, the accuracy of the calculated "erosion" volume was a little lower than expected, but certainly superior to what could be achieved through manual slope measurements of 3D surfaces for such minute erosion quantities – if it could be done at all. Volume inaccuracies are likely attributable to a small sample volume relative to error accumulation, minute surface misalignment, or slight inaccuracies when measuring the reference distance in the field or setting marker targets within PhotoScan.

6 Conclusions and Future Research

Initial results indicate that the utility of photo-based orthomapping and 3D terrain modeling is well-suited for some types of hydrology work, but is not a replacement for terrestrial or aerial LiDAR for vegetated sites. One overall advantage of photo-based terrain modeling techniques is the inclusion of photo texturing.

TS1-Field: In this investigation, the Zephyr flying wing used in combination with PhotoScan software to model drainage networks for sites less than 250 hectares, did not yield better results than 2 m LiDAR data at a coarser XY resolution. Because of its potentially high utility, further investigations will be conducted to determine if PhotoScan accuracy can be improved, most notably by using more aerial photographs from multiple flight passes and better ground control. Unlike bare-earth processing available in LiDAR, vegetation may be an insurmountable issue for some sites if using PhotoScan.

TS2-Prairie Gulley: Using a low flying hexacopter proved to be an efficient method to collect aerial imagery for gully modeling. From low altitude (16 m) photographs, PhotoScan was capable of producing terrain models within a mean ±3.53 cm of spot field measurements. Future investigations will deploy this new tool to regularly scheduled gully research work. More rigorous testing and positional control consistently applied across erosion monitoring events will be compared to manual cross section techniques. Again, vegetated gullies are anticipated to be problematic, but attempts will be made to efficiently edit point clouds to remove vegetation from the terrain models.

TS3-Eroded Slope: Even with minimal control, PhotoScan is capable of resolving minute changes (±5 mm) in terrain surfaces useful for monitoring erosion. Initial investigations demonstrated that accuracy of at least 85.8% can be achieved when estimating erosion quantities. Future investigations will review the procedure protocol to isolate error sources and seek to improve accuracy to 95% or better. Larger and more complicated gully configurations will also be tested.

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